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Original Research Article

Change in resting metabolic rate in rugby athletes during a rugby preseason – do increases in skeletal muscle mass increase athlete energy expenditure?

MacKenzie-Shalders, Kristen L.¹; Byrne, Nuala M.²; King, Neil A.³; and Slater, Gary J⁴.

1. Bond University, Bond Institute of Health and Sport, Faculty of Health Sciences and Medicine (Gold Coast, Australia)
2. University of Tasmania, School of Health Sciences, College of Health and Medicine (Launceston, Australia)
3. Queensland University of Technology, Institute of Health and Biomedical Innovation, School of Exercise and Nutrition Sciences, (Brisbane, Australia)
4. University of the Sunshine Coast, School of Health and Sport Sciences (Sippy Downs, Australia)

Key words: Energy prediction, Resting Metabolic Rate, Rugby athletes, indirect calorimetry.

Corresponding Author: Dr Kristen MacKenzie-Shalders

c/o Bond Institute of Health & Sport

Faculty of Health Sciences & Medicine, Bond University.

2 Promethean Way, Robina.

4226 Australia

kmackenz@bond.edu.au

+61 7 55951018

Abstract

Optimising dietary energy intake is essential for effective sports nutrition practice in rugby athletes. Effective dietary energy prescription requires careful consideration of athletes' daily energy expenditure with the accurate prediction of resting metabolic rate (RMR) important due to its influence on total energy expenditure and in turn, energy balance. This study aimed to (a) measure rugby athletes RMR and (b) report the change in RMR in developing elite rugby players over a rugby preseason subsequent to changes in body composition and (c) explore the accurate prediction of RMR in rugby athletes. Eighteen developing elite rugby union athletes (age 20.2 ± 1.7 years, body mass 101.2 ± 14.5 kg, stature 184.0 ± 8.4 cm) had RMR (indirect calorimetry) and body composition (dual energy x-ray absorptiometry) measured at the start and end of a rugby preseason ~14 weeks later. There was no statistically significant difference in RMR over the preseason period (baseline 2389 ± 263 kcal·day⁻¹ post 2373 ± 270 kcal·day⁻¹) despite a significant increase in lean mass of $+2.0 \pm 1.6$ kg ($P < 0.01$) and non-significant loss of fat mass. The change in RMR was non-significant and non-meaningful; thus, this study contradicts the commonly held anecdotal perception that an increase in skeletal muscle mass will result in a significant increase in metabolic rate and daily energy needs. Conventional prediction equations generally under-estimated rugby athletes' measured RMR and updated population-specific prediction equations may be warranted.

Keywords: Metabolism, Nutrition, Measurement, Prediction, Team Sport.

Introduction

Optimising dietary energy intake is fundamental for athletic populations and is necessary for successful sports nutrition interventions. In athletes, adjustment in energy intake is an important component of interventions targeting manipulation of body composition, glycogen replenishment and hormonal or metabolic adaptations (Tharion et al., 2005). The effective prescription of dietary energy intake in practice requires careful consideration of athletes' daily energy expenditure including their resting metabolic rate (RMR), activity energy expenditure (AEE) and dietary induced thermogenesis (DIT). RMR makes up a significant component of daily energy expenditure, irrespective of total training load. Several prediction equations are commonly applied to predict RMR due to a strong, linear relationship between body mass (BM) and/or lean body mass (LBM) and RMR. However, these are largely sampled from non-athlete

populations and are based on data collected up to 100 years ago thus failing to account for secular changes in body composition (Cunningham, 1991; De Lorenzo, Bertini, Candeloro, & Piccinelli, 1999; Harris & Benedict, 1919; Roza & Shizgal, 1984; Schofield, 1985).

It is possible that rugby athletes with high training loads and a high LBM, predominantly from increased skeletal muscle mass, may have their energy requirements over-estimated by traditional linear prediction methods. Point-in-time or cross-sectional studies do not consider the effect of training-induced adaptations on RMR. In addition, while LBM contributes a large proportion (50 – 70 %) of individual variations in RMR (Westerterp, Meijer, Janssen, Saris, & Ten Hoor, 1992), it has been shown that at higher levels of LBM there is a tapered (diminished) slope for RMR than at lower values (Javed et al., 2010; Nelson, Weinsier, Long, & Schutz, 1992). This may be because skeletal muscle mass is less metabolically active than the other lean tissues, such as internal organs, and has the lowest energy usage per gram at rest of all lean tissues (Kistorp, Toubro, Astrup, & Svendsen, 2000; Midorikawa, Kondo, Beekley, Koizumi, & Abe, 2007; Müller, Bosy-Westphal, Kutzner, & Heller, 2002; Pourhassan et al., 2015; Svendsen, Hassager, & Christiansen, 1993). Based on these relationships, it has been suggested that allometric scaling may be an appropriate avenue for energy prediction in athlete populations at higher lean mass or body mass values than traditional linear models (Slater & Phillips, 2011).

The Cunningham (linear) equation which is commonly recommended for athlete groups predicts that for every kg increase in fat-free mass or LBM (inclusive of bone mineral) RMR will increase by 22 kcal ($\sim 92 \text{ kJ} \cdot \text{day}^{-1}$) (Jagim et al., 2017; ten Haaf & Weijs, 2014). Based on this premise, there is a commonly held anecdotal belief that increasing LBM will increase energy expenditure and have implications for energy balance and body composition management. To our knowledge there are no studies in male rugby athletes documenting changes in RMR – and the effective prediction of RMR - in conjunction with changes body composition during a rugby preseason.

Therefore, the aims of this study were to (a) measure rugby athletes RMR when undertaken following standard protocols (Compher, Frankenfield, Keim, & Roth-Yousey, 2006), (b) to report the change in RMR in developing elite rugby players over a rugby preseason in conjunction with changes in body composition and (c) explore the accurate prediction of RMR through several traditional prediction equations and a new regression equation specific to the study population.

Methodology

A convenience sample of eighteen developing elite rugby union athletes (age 20.2 ± 1.7 years, body mass 101.2 ± 14.5 kg, stature 184.0 ± 8.4 cm) were recruited as a subsection of a group completing an observational study assessing dietary intake and changes in body composition over a rugby preseason (MacKenzie, Slater, King, & Byrne, 2015). At the start of the preseason, the athlete participants presented for an assessment of body composition and resting metabolic rate. This was repeated ~14 weeks later. Participants were encouraged not to change their usual training program, supplementation program and dietary intake during the study as discussed elsewhere (MacKenzie et al., 2015). All participants provided consent and were informed that they could withdraw from the project without any repercussions from their rugby program, rugby support staff, the researchers or Queensland University of Technology. Human Research Ethics Clearance was obtained by the Queensland University of Technology Human Research Ethics Committee (QUT Ethics Approval Number 1100000852).

Body composition

The participants presented to the laboratory in an overnight fasted state and were required to void their bladder upon arrival. Stretch stature was measured on a wall-mounted stadiometer (Harpenden, HAR- 98.602, Holtain. Limited, Crymych, Dyfed) to the nearest 0.1 cm, using standard procedures (Marfell-Jones & Stewart, 2012). Weight and body composition was measured by Dual-Energy X-ray Absorptiometry (DXA) with Lunar Prodigy Advance (Encore Version 13.60 software). All participants were scanned on thick mode and two half scans were used on all participants as has been discussed elsewhere (MacKenzie et al., 2015). A radioluminescent strap was placed around the ankles to restrict movement and standardise positioning on the scanner, in accordance with guidance of the International Society for Clinical Densitometry (Hangartner, Warner, Braillon, Jankowski, & Shepherd, 2013). Regions of interest were confirmed and the same trained operator undertook analyses. Quality control procedures were undertaken prior to testing each morning in accordance with manufacturer's specifications.

Indirect Calorimetry

On a separate day to the body composition measurement, RMR was measured in the morning after a minimum of 8 hours fasting and at least 10 hours after exercise. Athletes were advised to avoid strenuous exercise on the day prior and avoid physical activity above that required to travel to the laboratory by car on the morning of the measurement. Measures were taken over 30 minutes via indirect calorimetry (TrueOne® 2400 Metabolic Measurement System, ParvoMedics Inc) using a ventilated hood system. RMR was calculated from the average of respiratory exchange data corresponding with the lowest oxygen consumption over ten consecutive minutes of the thirty-minute measurement period. Participants were permitted to listen to quiet music, and participants were advised to breathe normally and stay as rested as possible without falling asleep. Resting heart rate was measured separately using a heart rate monitor and chest strap (Polar Electro Oy, Kempele, Finland). RMR was reported as an absolute measure ($\text{kcal}\cdot\text{day}^{-1}$) and relative to body mass ($\text{kcal}\cdot\text{kg BM}\cdot\text{day}^{-1}$) and lean body mass ($\text{kcal}\cdot\text{kg LBM}\cdot\text{day}^{-1}$). Quality control procedures were undertaken prior to testing each morning in accordance with manufacturer's specifications.

Analysis

Statistical analysis was performed using SPSS statistical software (SPSS 23.0, Chicago, IL). All data are presented as means \pm SD. Linear regression and/or correlational analyses were determined between body mass and lean mass values with RMR and reported as the coefficient of determination (R^2) and the standard error of the estimate (SEE). Pre and post measures for RMR and other key variables including body mass, lean mass, fat mass, the respiratory quotient and heart rate were compared by paired sample t-tests and reported with significance ($P < 0.05$) and 95% confidence intervals. Regression equations were derived from baseline body composition data and were applied to body composition data and measured RMR at the end of the preseason.

RESULTS

Table 1 describes the body composition and metabolic assessment of athletes during the preseason period. There was no significant change in RMR ($\text{kcal}\cdot\text{day}^{-1}$) during the ~14 week rugby preseason. The rugby athletes had a significant increase in LBM ($P < 0.01$) and

significant decrease in resting heart rate ($P < 0.05$). Measured RMR at baseline was positively correlated with measured RMR post preseason ($R^2 = 0.92$; $P < 0.001$, $SEE = 78.701$).

Insert table 1 approximately here

At all time points there was a moderate to strong correlation between BM and RMR (baseline; $R^2 = 0.78$; $P < 0.001$, $SEE = 127.6$ and post preseason; $R^2 = 0.76$; $P < 0.001$, $SEE = 137.3$) and LBM and RMR (baseline; $R^2 = 0.82$; $P < 0.001$, $SEE = 115.9$ and post preseason; $R^2 = 0.82$; $P < 0.001$, $SEE = 116.2$). Scatterplots of LBM and BM with RMR and their linear regression equations are featured in Figure 1 and Figure 2.

Insert Figure 1 & Figure 2 approximately here

Table 2 summarises predicted RMR using regression equations derived from baseline body composition data compared to measured RMR at baseline and post preseason. In addition, it shows RMR predicted by commonly applied prediction equations using baseline data in comparison to measured RMR at baseline and post preseason. When regression equations derived from baseline BM were used to predict RMR at post preseason, there was no significant difference between measured and predicted RMR. However, when regression equations using baseline LBM - or LBM and FM combined - were used to predict post preseason RMR there was a significant difference between predicted and measured RMR.

For the prediction equations derived from baseline data, the SEE was less and R^2 was higher for the prediction equation using LBM and FM in comparison to BM or LBM as individual predictors.

Insert Table 2 approximately here

Both sampled BM-derived prediction equations i.e. Harris-Benedict 1 (Harris & Benedict, 1919) and Harris-Benedict 2 (Roza & Shizgal, 1984)) and the LBM-derived Cunningham equation (Cunningham, 1991) using baseline data significantly under-predicted measured RMR at baseline and post preseason.

DISCUSSION

A key finding of this study was that after a small but significant increase in LBM (~2 kg or ~2.5% on average) there was no corresponding change in the measured RMR during a ~14-week preseason in developing rugby athletes. The change in RMR across the preseason was non-significant ($P < 0.05$) and non-meaningful (Roffey, Byrne, & Hills, 2006). This finding

supports previous studies which have shown decreases or no change in RMR as a result of chronic adaptations to endurance (Byrne & Wilmore, 2001; Lee, Sedlock, Flynn, & Kamimori, 2009; Morio et al., 1998; Scharhag-Rosenberger, Meyer, Walitzek, & Kindermann, 2010) or resistance training programs (Ryan, Pratley, Elahi, & Goldberg, 1995). In addition, the findings of the current study contradict the common anecdotal suggestion that increased lean mass through increases in skeletal muscle mass will substantially increase metabolic rate and daily energy expenditure.

As expected, there was a strong linear relationship between RMR and both BM and LM. Measured RMR post preseason did not differ from RMR predicted from the RMR-BM regression equation developed from baseline data. However, the measured RMR post-preseason was less than that predicted from the LBM-RMR or LBM and FFM-RMR prediction equation developed at baseline. This is perhaps unsurprising given there was no significant change in body mass, merely an increase in lean body mass with a concomitant decrease in body fat during the pre-season. However, this finding may highlight the error associated with the simplification of prediction by the lean tissue compartment – made up of highly variant tissues - while ignoring chronic training-induced metabolic adaptations, including chronic energy availability and energy flux into the muscle, that can impact on athletes' RMR (Broeder, Burrhus, Svanevik, & Wilmore, 1992; Burke, Bullough, & Melby, 1993; Lemmer et al., 2001).

For the baseline-derived prediction equations – the standard error of the estimate was less and R^2 was higher (i.e. the equation better represented the data) for the prediction equation using LBM and FM in comparison to BM or LM as individual predictors. The LBM-derived traditional prediction equation i.e. Cunningham equation (Cunningham, 1991) was more effective in predicting RMR than the traditional BM-derived regression equations i.e. Harris-Benedict 1 (Harris & Benedict, 1919) and Harris-Benedict 2 (Roza & Shizgal, 1984). All of these sampled prediction equations under-predicted the rugby athletes' measured RMR, suggesting population specific prediction equations using updated body composition assessment methods may be useful to inform sports nutrition prescription for athlete groups. In addition, there was a high degree of variability in the results with some individuals RMR being over-predicted in comparison to others, suggesting nuances between the RMR and body composition of the individuals.

It is acknowledged that the sample size was relatively small as this study was undertaken in elite junior rugby athletes. While regression equations were developed based on this study, as a small sample of relatively homogenous rugby athletes undertaking similar training there should be some caution applying them to other population groups. Due to a small sample size and large spread of body composition characteristics, it is also difficult to determine whether there was a tapered (diminished) slope for RMR at higher BM or LM values. This can only be conclusively supported by larger scale, targeted studies.

A limitation of the study was that dietary intake (and thus energy balance) were not measured or controlled on the day prior to RMR measurement. In addition, within this study a minimum of 10 hours, but typically 12 – 14 hours after training was allocated for the RMR measurement in line with evidence of 2 hours of abstention from moderate aerobic exercise (Grade II – fair) and 14 hours for vigorous exercise (Grade III – limited) as advised for non-athletes (Compher et al., 2006) though there is conjecture on the time frame required for RMR to normalise after different training types (Fullmer et al., 2015). Notably, training may substantially influence RMR in trained individuals and trained individuals' RMR returns more rapidly to baseline after physical activity (Børsheim & Bahr, 2003; Short & Sedlock, 1997; Tremblay, Nadeau, Fournier, & Bouchard, 1988). Athletes were advised to avoid strenuous exercise on the day prior of the measurement and avoid activity above that required to travel to the laboratory immediately prior to the measurement. There was no clear indication that the rugby athletes' measured RMR was higher than expected and it is common for athlete energy requirements to be under-predicted by traditional prediction equations (De Lorenzo et al., 1999; Loureiro et al., 2015; Manore & Thompson, 2006; Sjodin et al., 1996; Thompson & Manore, 1996).

This study has demonstrated that rugby athletes have a high energy expenditure at rest and that individual changes in lean body mass had a negligible impact on changes in RMR in a group of rugby athletes during a preseason. This study contradicts the common anecdotal suggestion that increased lean mass through increases in skeletal muscle mass will substantially increase metabolic rate and daily energy needs. It also challenges the perception that the modest increases in lean body mass commonly reported amongst individuals undertaking resistance training, will markedly influence metabolic rate. These examples highlight the need for future research using large homogenous athlete samples to assess the relationships between training, resting metabolic rate, body mass, lean body mass, fat mass, organ mass, regional body

composition, and potentially other metabolic factors unique to athletes that may influence RMR.

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Table 1. Changes in body composition, RMR, heart rate and RQ measurements in rugby athletes during a ~14 week preseason.

N= 18	Baseline preseason measure Mean & SD	Post preseason measure Mean & SD	Change value ~ 14 weeks	95% Confidence Interval	Significance (P value)
Body Mass (kg)	101.6 ± 14.5	103.1 ± 12.9	+ 1.5 ± 2.6	0.2 – 2.8	0.03
Lean Body Mass (kg)	81.3 ± 8.0	83.2 ± 8.4	+ 2.0 ± 1.6	1.2 – 2.8	< 0.01
Fat mass (kg)	20.4 ± 8.7	19.9 ± 7.2	- 0.5 ± 2.4	- 1.7 – 0.7	0.40
RMR (kcal·day ⁻¹)	2389± 263	2373± 270	- 16 ± 79	-55 – 23	0.39
Resting HR (bpm)	54 ± 5	52 ± 6	- 3 ± 4	-5 – -1	0.02
Resting RQ	0.70 ± 0.04	0.74 ± 0.36	+ 0.04 ± 0.04	0.02 – 0.05	< 0.01

Resting Metabolic Rate (RMR), Heart Rate (HR), Respiratory Quotient (RQ).

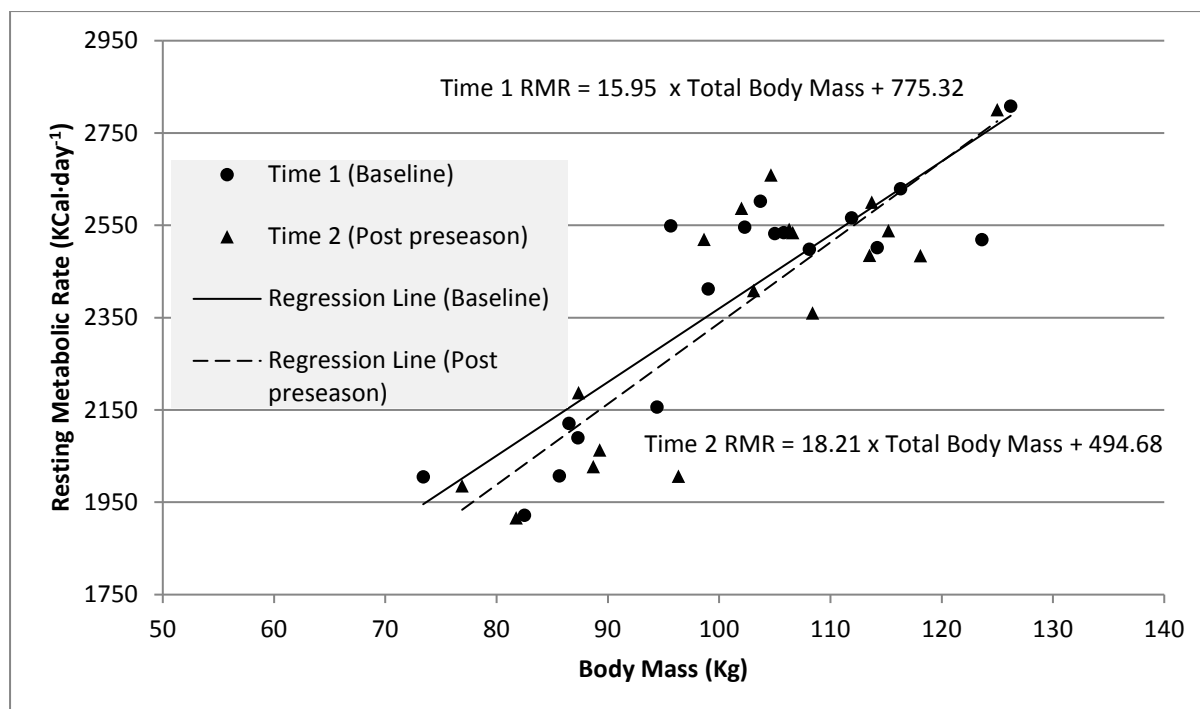


Figure 1. Scatterplot and line of best fit between BM (kg) and RMR (kcal·day⁻¹) in rugby athletes at baseline and post preseason ~ 14 weeks later.

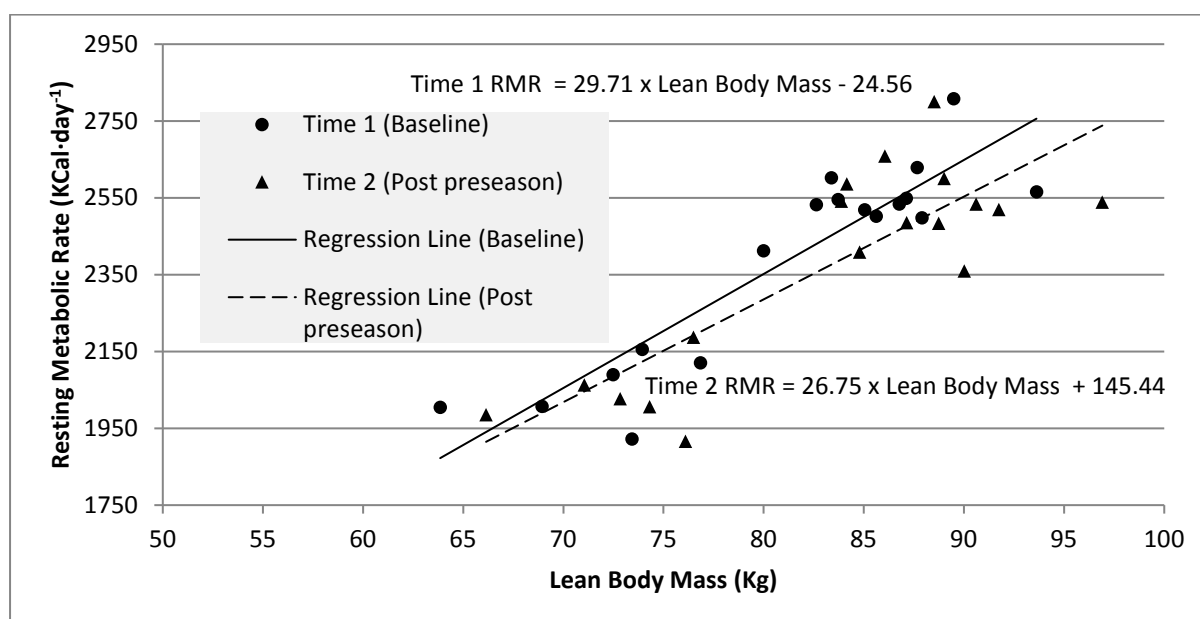


Figure 2. Scatterplot between LBM (kg) and RMR (kcal·day⁻¹) in rugby athletes baseline and post preseason ~ 14 weeks later.

Table 2: Comparison of developing rugby athletes' predicted RMR using prediction equations derived from baseline body composition data in comparison to measured RMR using indirect calorimetry at the start and the end of the pre-season^a.

N= 18	Measured RMR (Mean ± SD)	Predicted RMR using baseline BM-derived regression equation ^b (Mean ± SD)	Predicted RMR using baseline LBM-derived regression equation ^c (Mean ± SD)	Predicted RMR using baseline LBM & FFM derived regression equation ^d (Mean ± SD)	Predicted RMR using Cunningham Equation and baseline data ^e (Mean ± SD)	Predicted RMR using Harris Benedict 1 and baseline data ^f (Mean ± SD)	Predicted RMR using Harris Benedict 2 and baseline data ^g (Mean ± SD)
Baseline RMR (kcal·day ⁻¹)	2389 ± 263	2389 ± 232	2389 ± 237	2389 ± 244	2287 ± 176 (p = 0.004)	2242 ± 233 (p < 0.001)	2213 ± 226 (p < 0.001)
Post RMR (kcal·day ⁻¹)	2373 ± 270	2401 ± 210	2448 ± 250* (p = 0.047)	2436 ± 239 (p < 0.001)	2287 ± 176 (p = 0.03)	2242 ± 233 (p = 0.002)	2213 ± 226 (p < 0.001)

a. Paired samples t-test. Bolded text denotes significant difference between predicted and measured RMR.

b. $RMR = (15.95 \times BM) + 775.32$ ($R^2 = 0.78$, $SEE = 127.6$)

c. $RMR = (29.71 \times LBM) - 24.562$ ($R^2 = 0.82$, $SEE = 115.9$)

d. $RMR = (25.49 \times LBM) + (7.62 \times FM) + 162.93$ ($R^2 = 0.86$, $SEE = 103.3$)

e. $RMR = 500 + (22 \times LBM)$ (The Cunningham equation) (Cunningham, 1991)

f. $RMR = (13.7516 \times BM) + (5.0033 \times Stature) - (6.755 \times Age) + 66.4730$ (Harris-Benedict Equation 1) (Harris & Benedict, 1919)

g. $RMR = (13.397 \times BM) + (4.799 \times Stature) - (5.677 \times Age) + 88.362$ (Harris-Benedict Equation 2) (Harris & Benedict, 1919)

BM = Body Mass, LBM = Lean Body Mass, FM = Fat Mass.